ASHRAEJune07

JUNE 2007 STATUS
OF
NASA CLEAR-SKY RADIATION ESTIMATES
OVER THE GLOBE

by

Charles H. Whitlock, William S. Chandler, James M. Hoell, David J. Westberg, Taiping Zhang and Shashi Gupta
Science Systems and Applications, Inc., Hampton, VA, 23666-5845

Paul W. Stackhouse Jr. and Laura Hinkelman
Mail Stop 420, NASA Langley Research Center, Hampton, VA 23681-2199

A Special Report for the ASHRAE Technical Committee 4.2 on Climatic Information
ASHRAE 2007 Annual Meeting
Long Beach, CA
June 23-27, 2007

Sponsored
by the
NASA Applied Sciences Program, Earth-Sun System Division

INTRODUCTION

The NASA Prediction Of World Energy Resources (POWER) project first became aware of long-term needs in the buildings industry at a meeting in Charlottesville, VA in June of 2001. Attending were representatives from William McDonough + Partners (an architectural firm), 2rw Consultants, Inc. (an engineering firm), Old Mill Power Company (a renewable energy firm), and the Assistant Dean of the School of Engineering at the University of Virginia. Their major concern was the time it took to obtain weather and solar radiation data for a foreign country, particularly if the location was in a rural, underdeveloped area. Generally, they had 60 days to submit a preliminary-design proposal, and it was taking that long to obtain some foreign weather or radiation information. Their need was for a quick look at a complete set of preliminary weather and radiation data in order to develop and cost a preliminary building design within a short proposal time limit.

NASA has received requests for some buildings- and agricultural-related parameters from users of its Surface meteorology and Solar Energy web site (http://eosweb.larc.nasa.gov/sse) over the past 10 years. As a result, NASA provides global information on a few buildings-related parameters and is now working with ASHRAE to possibly assist their activities. This document expands on clear-sky solar radiation results that were provided to ASHRAE Technical Committee 4.2 in January 2007. In particular, it provides a graphics review of the surface and atmospheric data that are inputs to the Surface Radiation Budget Quality Check (SRBQC) analysis procedure. SRBQC is used to estimate 22-yr monthly average values of clear-sky radiation in all one-degree latitude/longitude cells over the globe.

SOURCES OF INFORMATION

Clear-sky results are based on NASA-developed broadband aerosol properties derived from MODIS 550 nm satellite data input to an assimilation process using 10 species of aerosols combined with Rayleigh and measured water vapor parameters over the globe. The assimilation process is the NCAR (National Center for Atmospheric Science) MATCH (Model for Atmospheric Transport and Chemistry). This information is combined with one-degree surface topography (figure 1); pressure and humidity information from GEOS-4 reanalysis data (figures 2 and 3); International Geosphere and Biosphere Program (IGBP) vegetation-type (figure 4); and surface albedos derived from the Earth Radiation Budget Experiment (ERBE) satellites (figures 5 and 6). Daily or monthly values are input to the SRBQC radiation transfer model daily over a 22-yr period. The SRBQC model is a satellite data analysis procedure that is used in both the NASA/GEWEX (Global Energy and Water Cycle Experiment) Surface Radiation Budget and the NASA Clouds and the Earth's Radiant Energy System (CERES) projects. Daily clear-sky estimates of surface broadband radiation are obtained from the SWQC model assuming cloud fraction is zero in daylight hours.

ACCURACY OF RESULTS

Clear-sky radiation values from the above satellite/solar radiation model process and aerosol combination have been tested against clear-sky ground site data from 27 World Meteorology Organization (WMO) Baseline Surface Radiation Network (BSRN) sites around the globe between 79 deg. North and 75 deg. South (Figure 7). Fifteen-minute clear-sky ground site BSRN data were furnished by the DOE Pacific Northwest National Laboratory. The fifteen-minute values were synthesized to full-day monthly averages at the NASA Langley Research Center. Monthly BSRN ground-site values of clear-sky downward shortwave radiation are compared with the SWQC Surface Shortwave Down (SWDN) estimates as shown in Figure 8. Daily values were also compared for two different definitions of clear-sky conditions. Figure 9 compares SRBQC and BSRN values when cameras at the ground site indicated that cloud fractions were less than 10 percent in the small region of the site. Figure 10 shows the same comparison except that clear skies must include a much larger one-degree latitude/longitude cell-size region that includes the site. SRBQC clear-sky estimates appear most representative of clear-sky regions larger than approximately 60 miles in diameter.

In 1989, WMO estimated that site-measured SWDN measurement uncertainties range from 6 % at research stations to as high as 12 % at some operational sites. In general, it appears that most SWQC clear-sky radiation values are inside the uncertainty range of ground site data.

AEROSOL PROPERTIES

An item of current interest to Technical Committee 4.2 is the aerosol properties used by the SWQC analysis process to obtain the above accuracies. Monthly maps of narrowband 550 nm Aerosol Optical Depth (AOD), broadband (200 to 4000 nm) AOD, and Broadband Single-Scattering Albedo (SSA) are shown in figures 11 through 22. Aerosol optical depths at the visible wavelength of 550 nm are much higher than broadband values averaged over the wider 200 to 4000 nm range. The SSA charts show movement of various types of aerosol plumes. SSA values above 0.9 suggest nearly-clear particles such as sea salt or very clear sand. Values below 0.9 indicate more absorbing particles such as smoke or darker sand or other particles which absorb more light. Broadband aerosol Asymmetry Parameter (ASP) values are not shown for reasons of brevity, but ranged in values from 0.68 to 0.78 depending on month and location.

These charts show large complex changes in both narrow band and broadband AOD and broadband SSA in some parts of the globe during the year, suggesting transient dust, sand, smoke, and industrial pollution events that influence clear-sky radiation. Much of this activity repeats itself from year-to-year in an approximate manner on a monthly basis. It is encouraging that these aerosol properties produced reasonably accurate results using the SRBQC analysis process as shown in figure 9.

TYPICAL CLEAR-SKY HISTORIES

Sample 22-year daily clear-sky histories for 4 sites near 40 degrees North latitude are provided in figure 23. Vertical scales are not always equal for each site in the figure. Care must be exercised when viewing the time-history charts. Values are not for the city indicated, but instead are for the nearest 1-degree cell to that city. It is clear that solar elevation angle is the most important parameter influencing clear-sky radiance which is well known. Monthly-average SRBQC aerosol properties (figures 11 through 22) are assumed the same for each year. Precipitable water varies as per GEOS-4 values on a daily basis over the period. The small daily variation that shows up on a year to year basis is probably related to precipitable water differences between years, not changes in aerosol properties. Rayleigh scattering and other absorbing gases are also contributors.

All four sites show about the similar minimum values (~2.5 kWh/m^2/day) for the winter. Summer peaks vary between the sites. Boulder, Colorado (figure 23, top chart) is the highest in altitude (figure 1) and has a low July aerosol optical depth (figure 17). Maximum summer values for broadband clear-sky irradiance are around 9.0 kWh/m^2/day. Indianapolis is lower than Ankura in altitude, but Ankura has a slightly higher broadband aerosol optical depth (figure 17). Summer clear-sky irradiances are approximately 8.0 for Indianapolis and 8.7 for Ankura. Beijing's altitude is similar to that of Indianapolis, but its broadband aerosol optical depth is much higher (figure 17). Peak summer clear-sky irradiances range between 7.3 and 7.8 on a yearly basis for Beijing. The average summer value for Indianapolis is around 8.0. It seems that site altitude is as important as broadband aerosol optical depth when attempting to estimate broadband clear-sky irradiances.

GLOBAL SUMMARY AND CONCLUDING REMARKS

The SRBQC clear-sky estimates may be summarized for the hottest months of the year as shown in figures 31 and 32. Figure 31 shows hottest months over the globe, and figure 32 has estimated values for clear-sky irradiance. Width of the color codes is probably indicative of the accuracy of the estimates.

Many meteorology sites do not have quality solar radiation measurements, particularly in rural regions. The NASA-developed broadband clear-sky estimates are not perfect, but uncertainties seem to be about the same as BSRN/PNNL-supplied ground site data. It is hoped that this type of broadband clear-sky information is useful to ASHRAE in development of its future data sets.

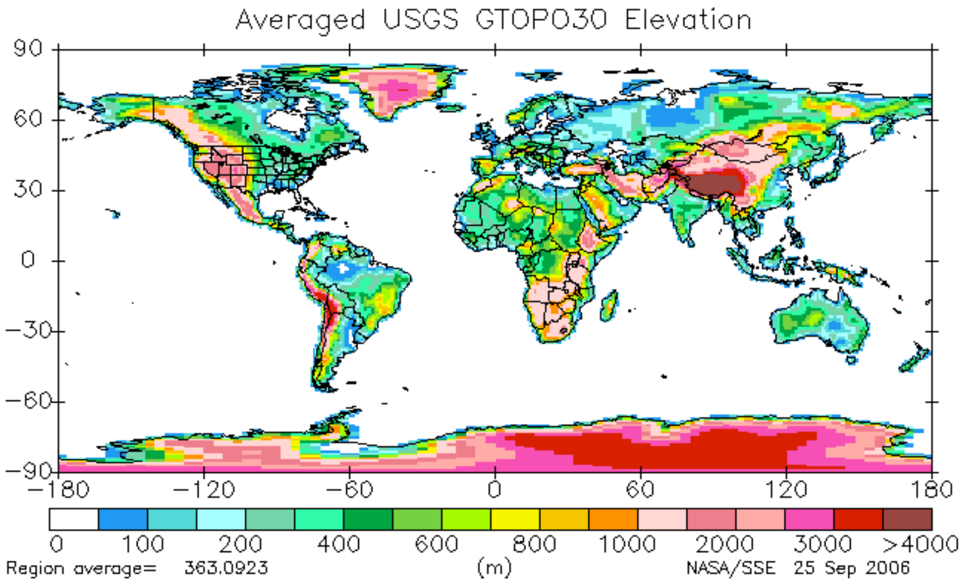


Figure 1. Topography used in NASA SRBQC analysis.

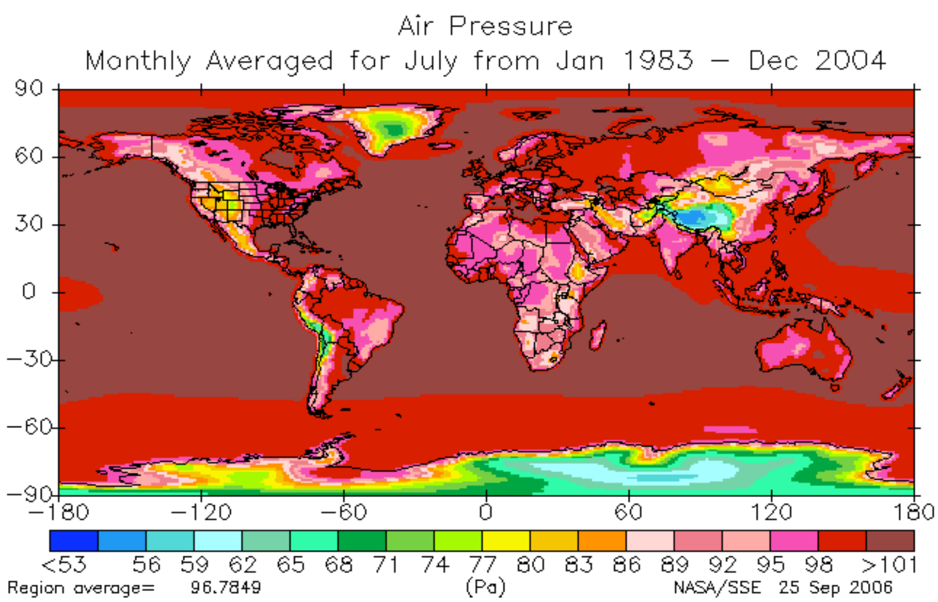


Figure 2. Air pressure in SRBQC analysis for July.

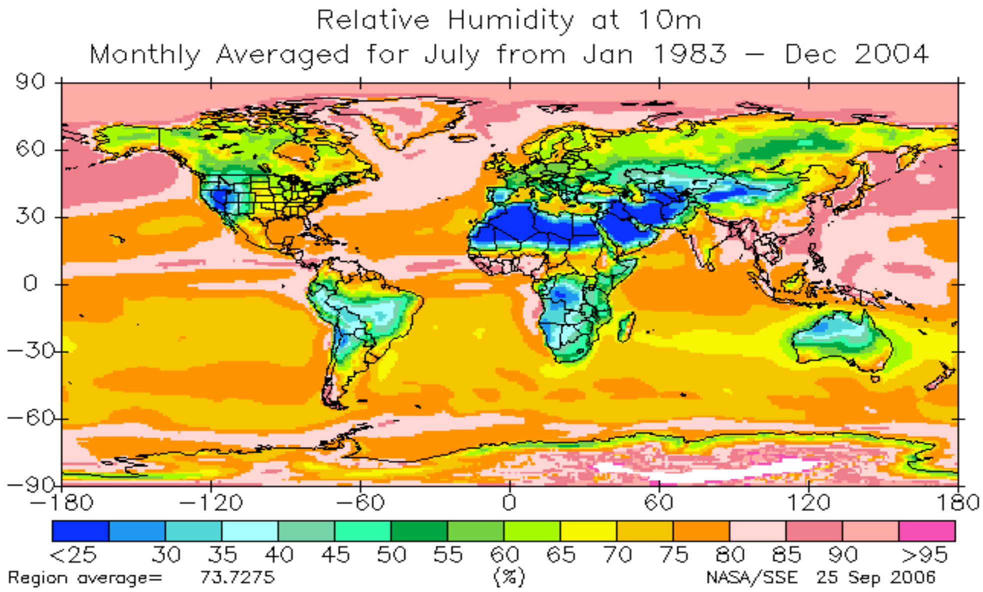


Figure 3. Relative humidity in SRBQC analysis for July.

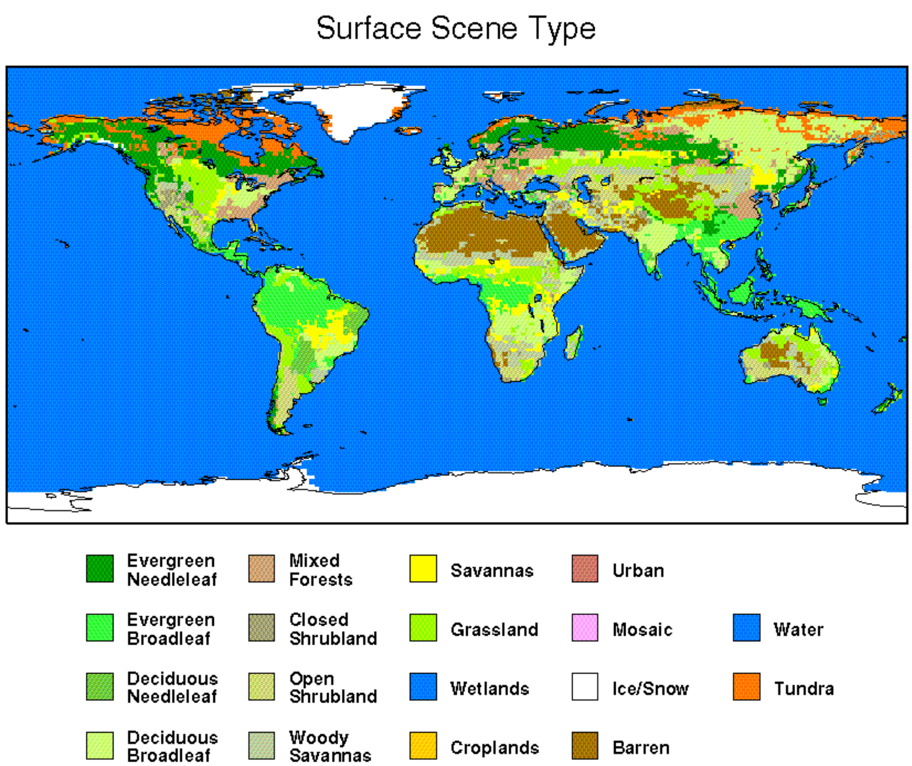


Figure 4. Scene types used in SRBQC analysis.

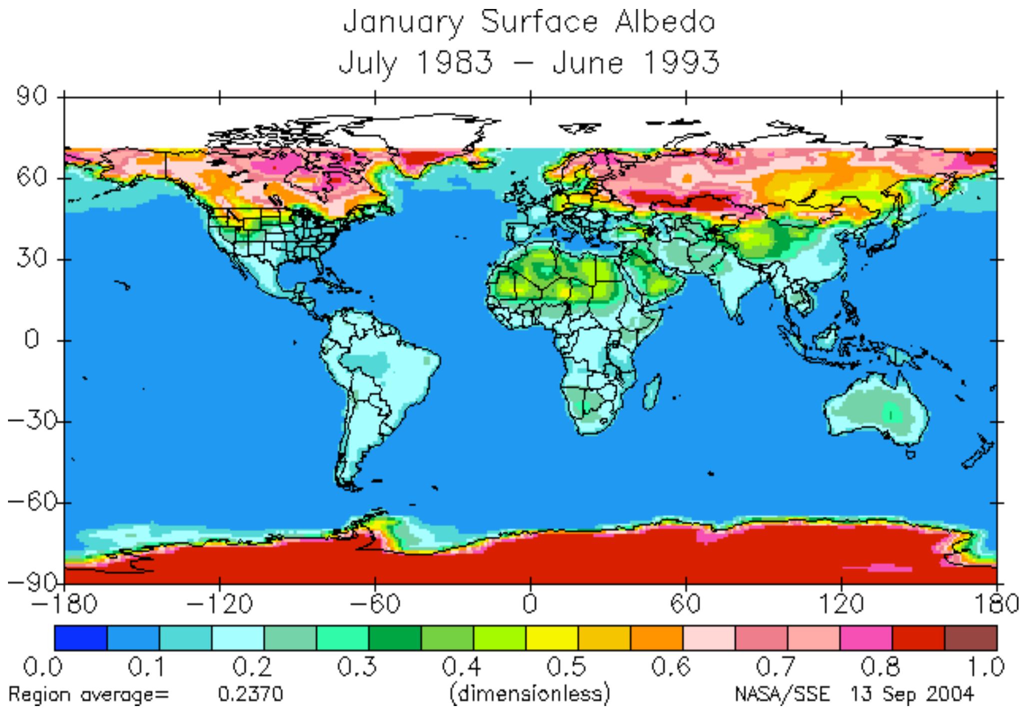


Figure 5. Surface albedo used in SRBQC analysis for January.

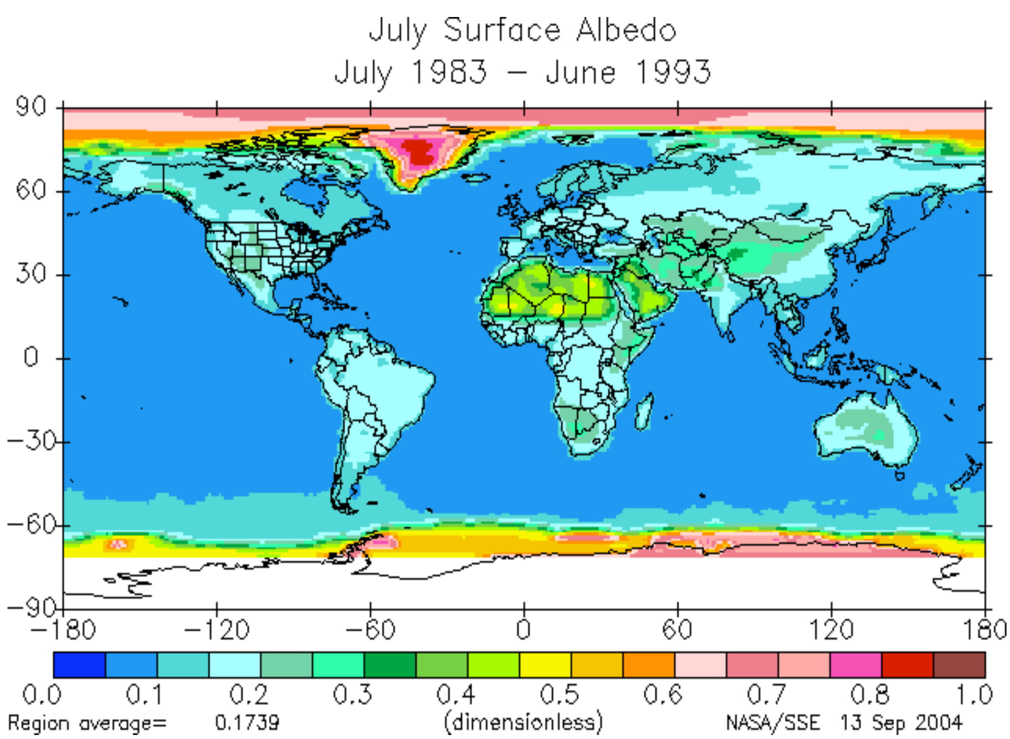


Figure 6. Surface albedo used in SRBQC analysis for July.

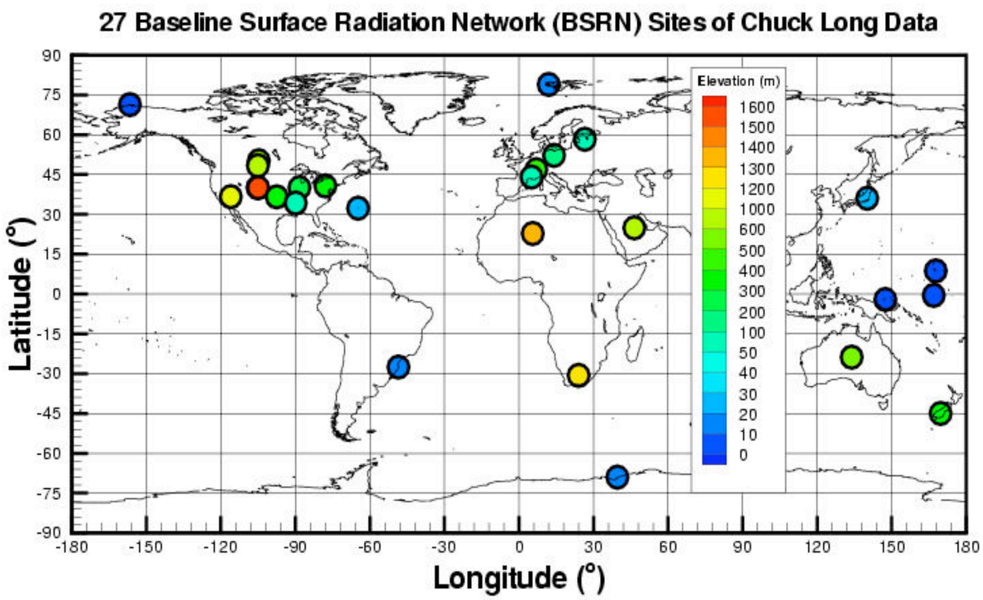


Figure 7: Map showing locations of 27 BSRN sites for which clear-sky data were furnished by DOE/Pacific Northwest National Laboratory.

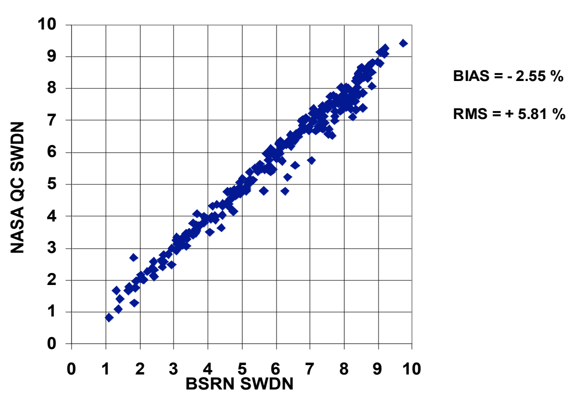


Figure 8: Monthly accuracy of clear-sky total short wave down (SWDN, kWh/m^2/day) on a horizontal surface.

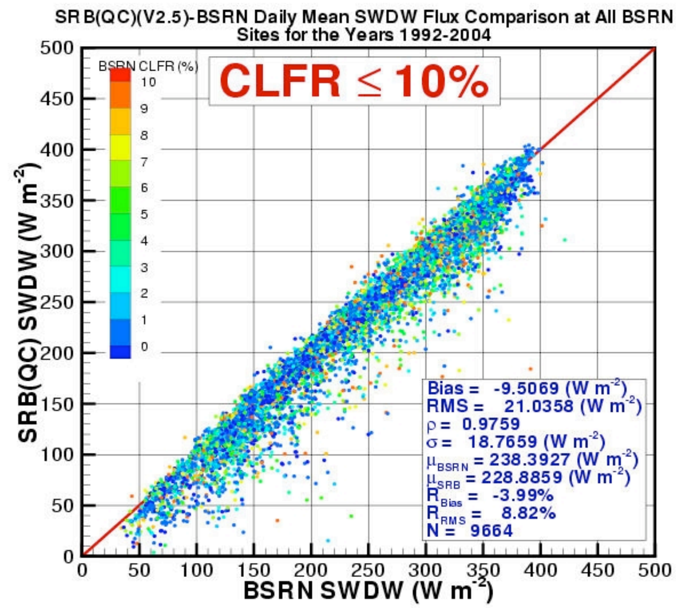


Figure 9. Daily accuracy of SRBQC SWDN when cloud fraction was less than 10 percent near the BSRN site as viewed by site camera data.

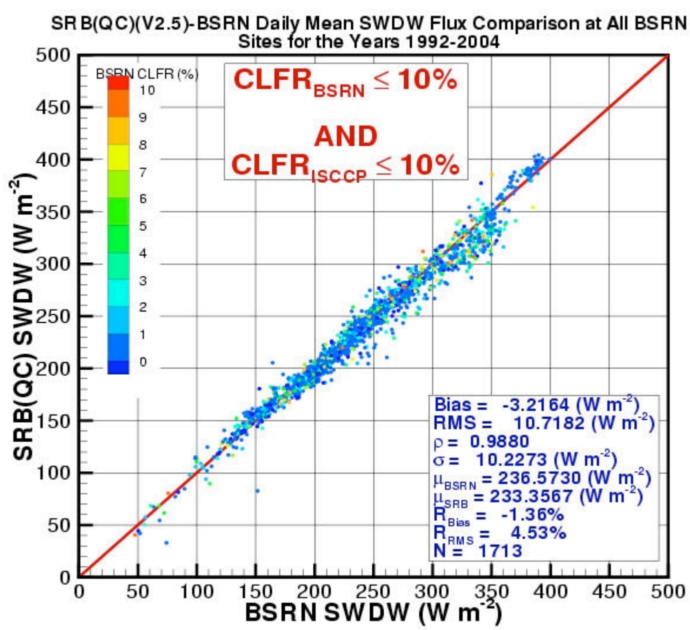
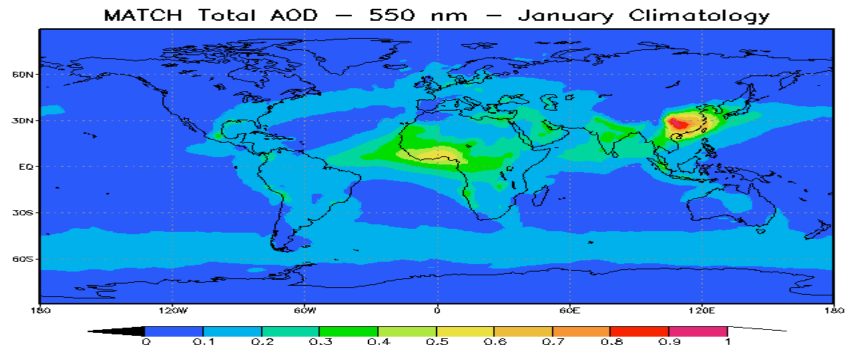
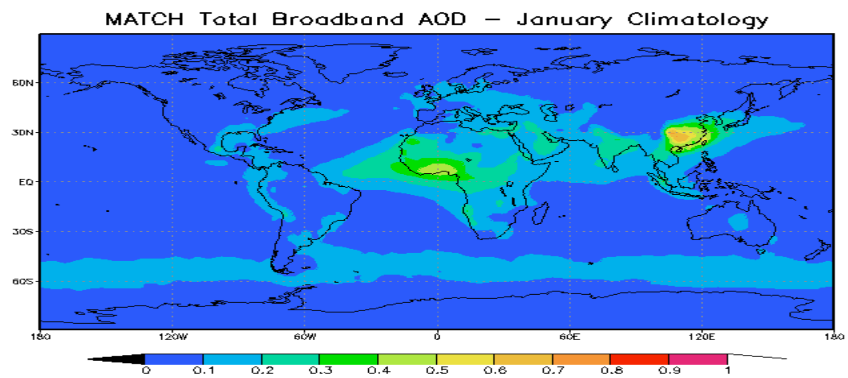


Figure 10. Daily accuracy of SRBQC SWDN when cloud fraction was less than 10 percent in both the small BSRN site area and the larger 1-degree latitude-longitude ISCCP satellite viewing region.





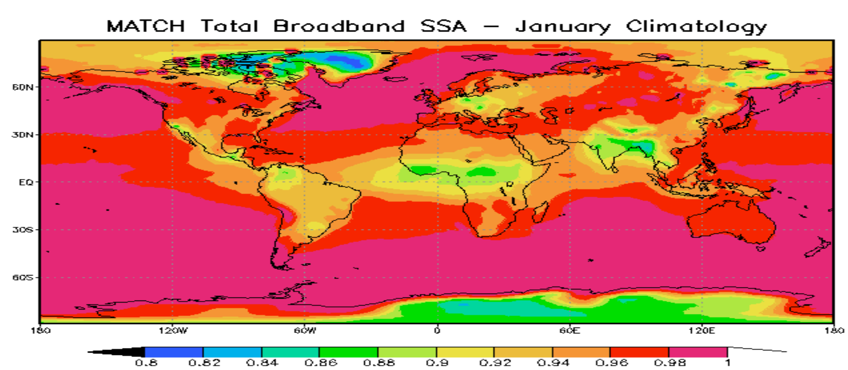


Figure 11. January Aerosol Climatology in SRBQC.

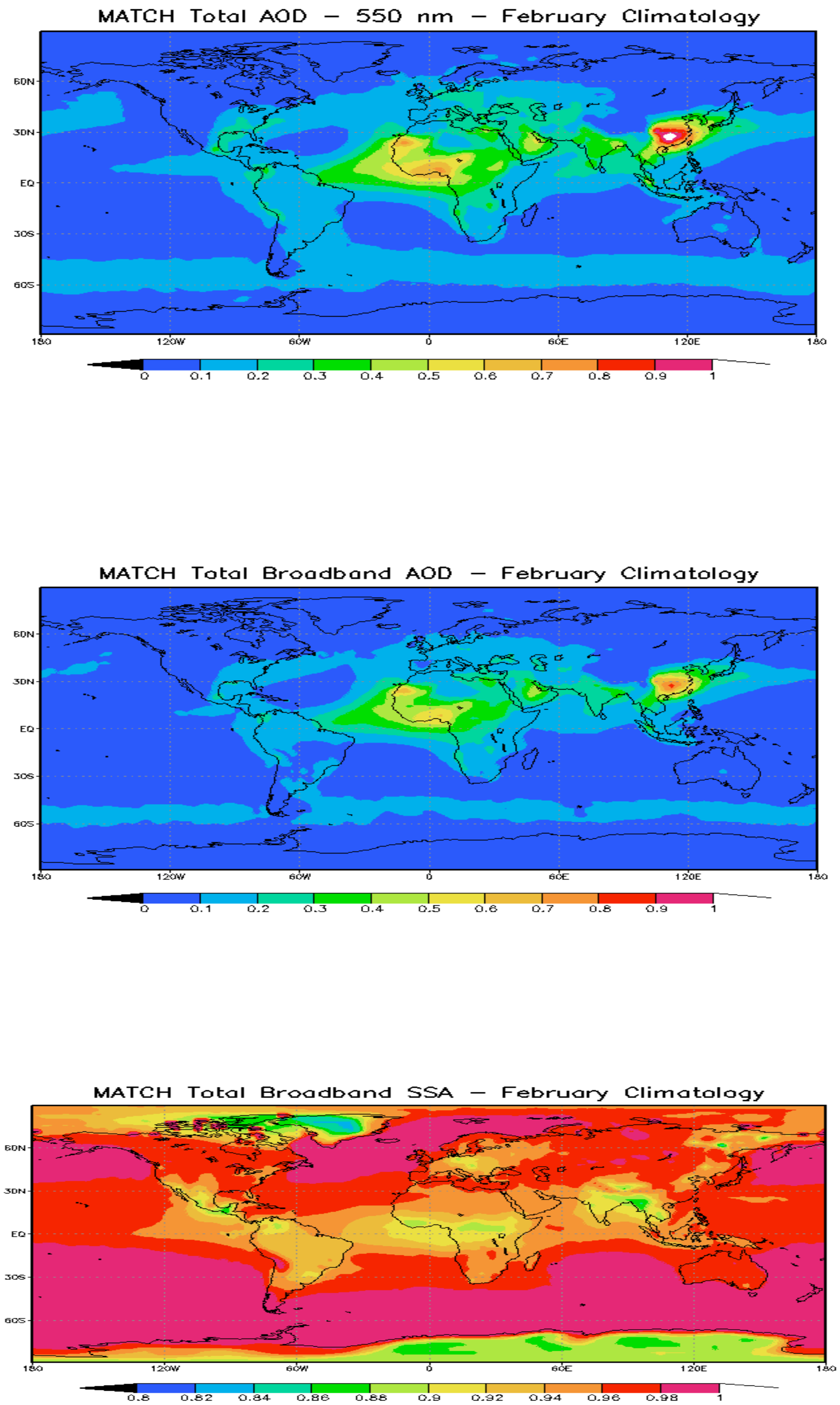


Figure 12. February Aerosol Climatology in SRBQC.

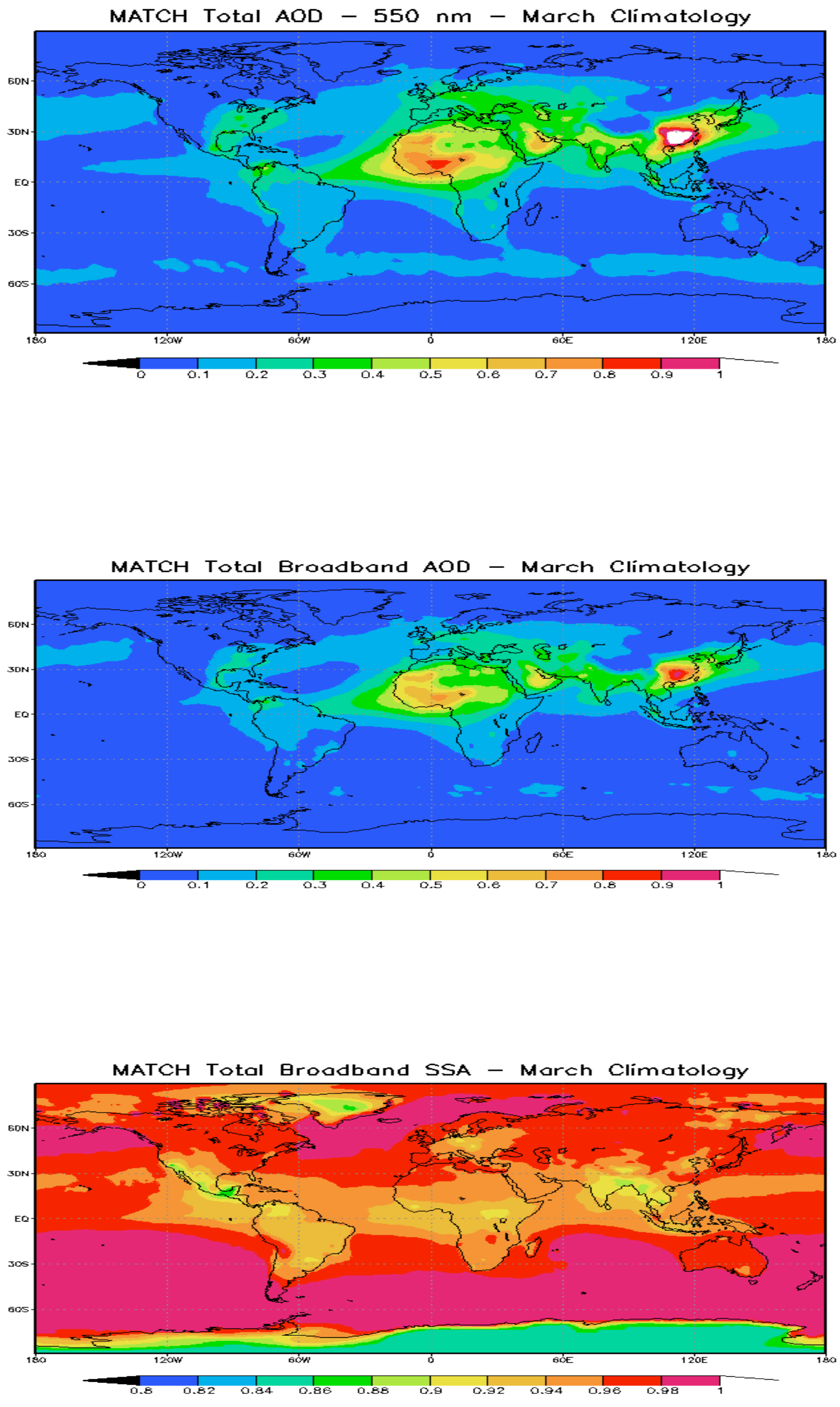


Figure 13. March Aerosol Climatology in SRBQC.

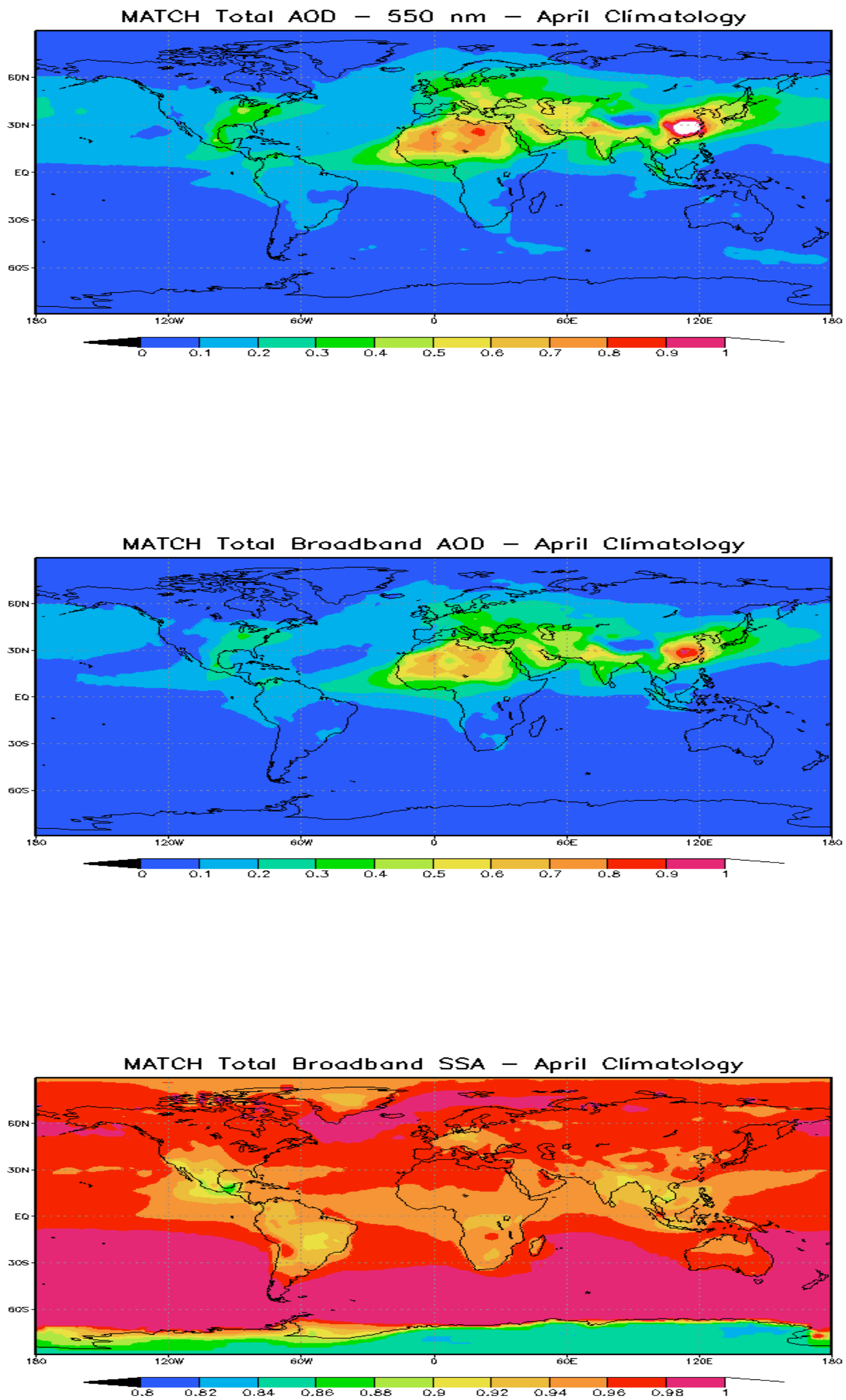


Figure 14. April Aerosol Climatology in SRBQC.

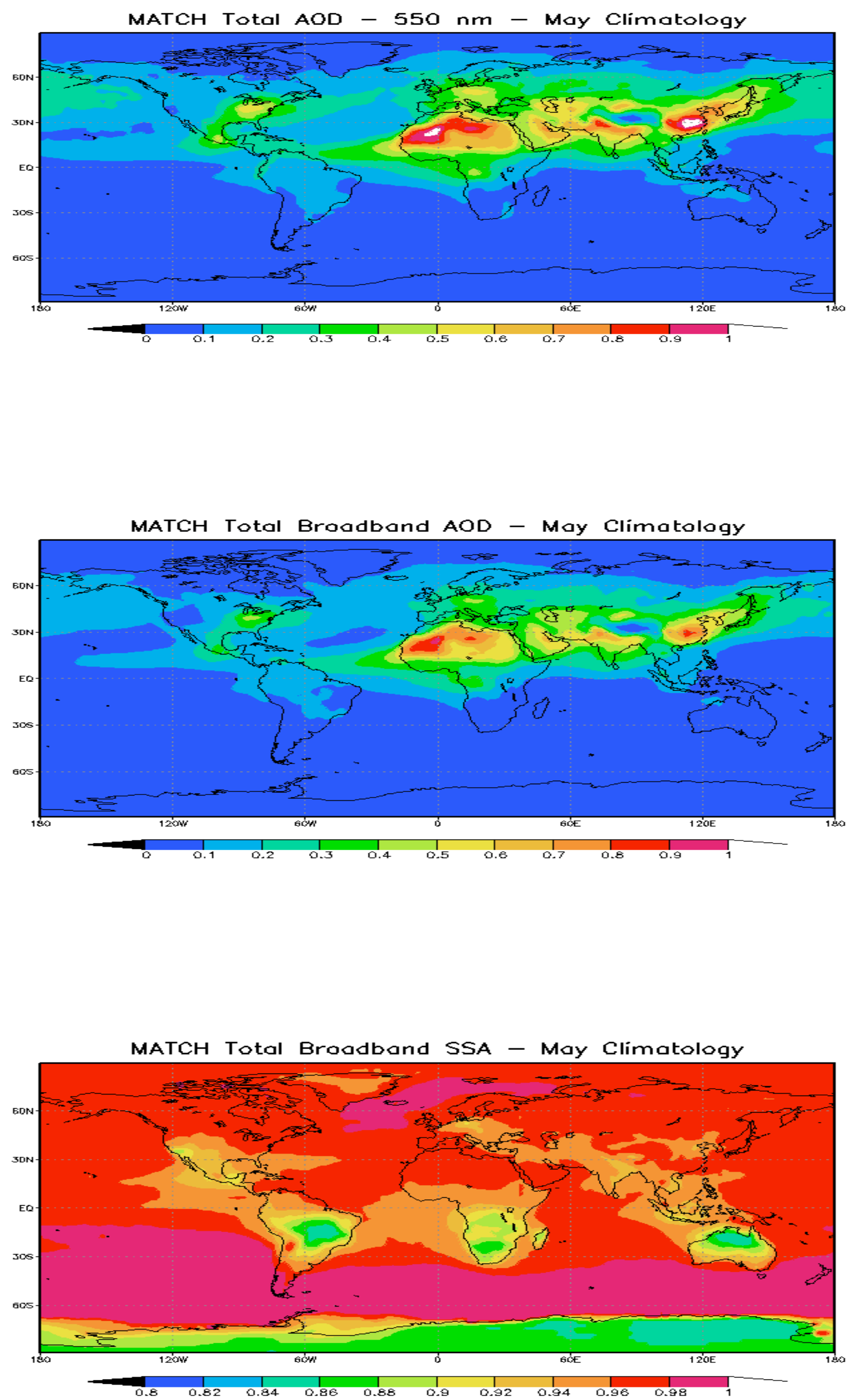


Figure 15. May Aerosol Climatology in SRBQC.

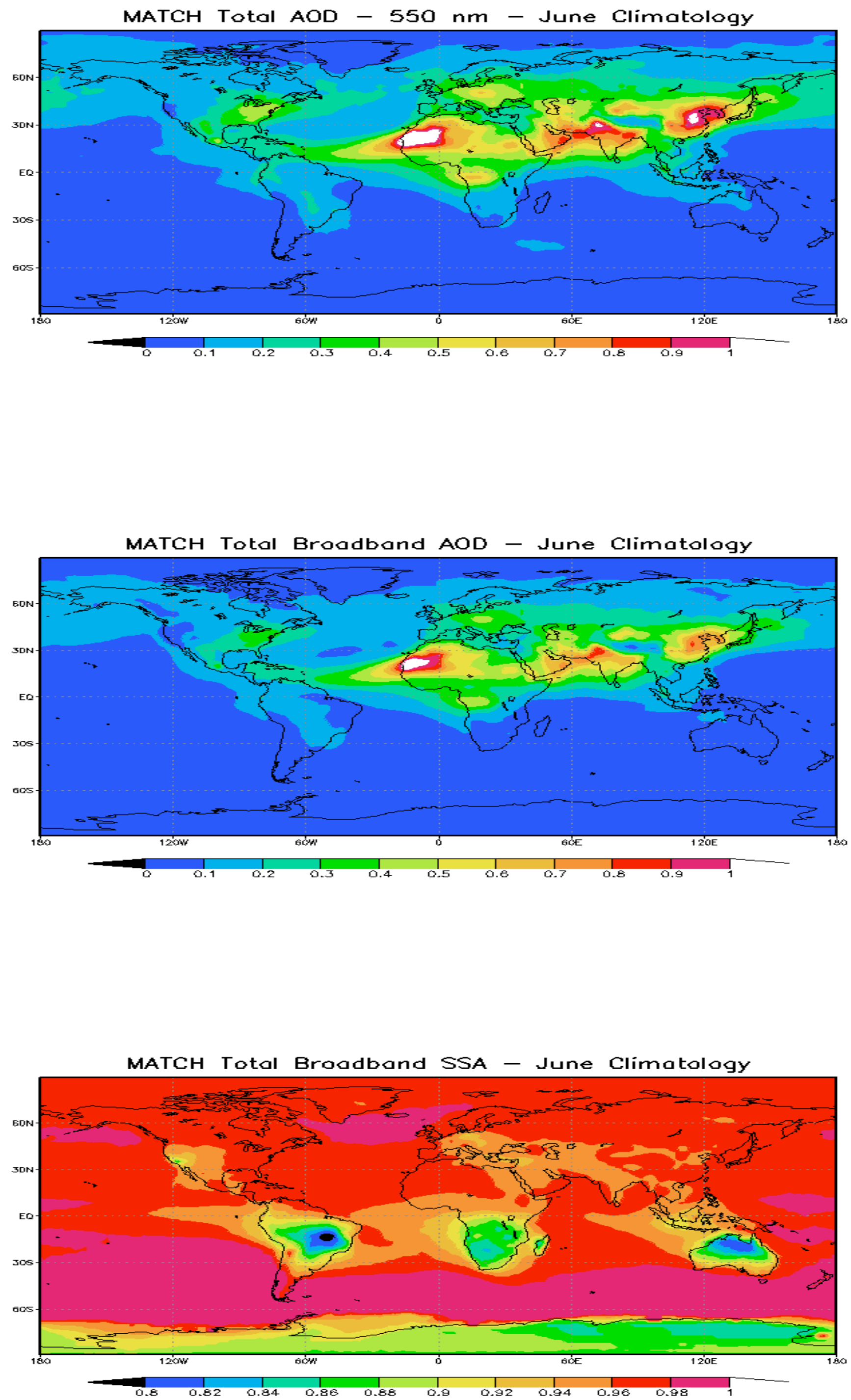


Figure 16. June Aerosol Climatology in SRBQC.

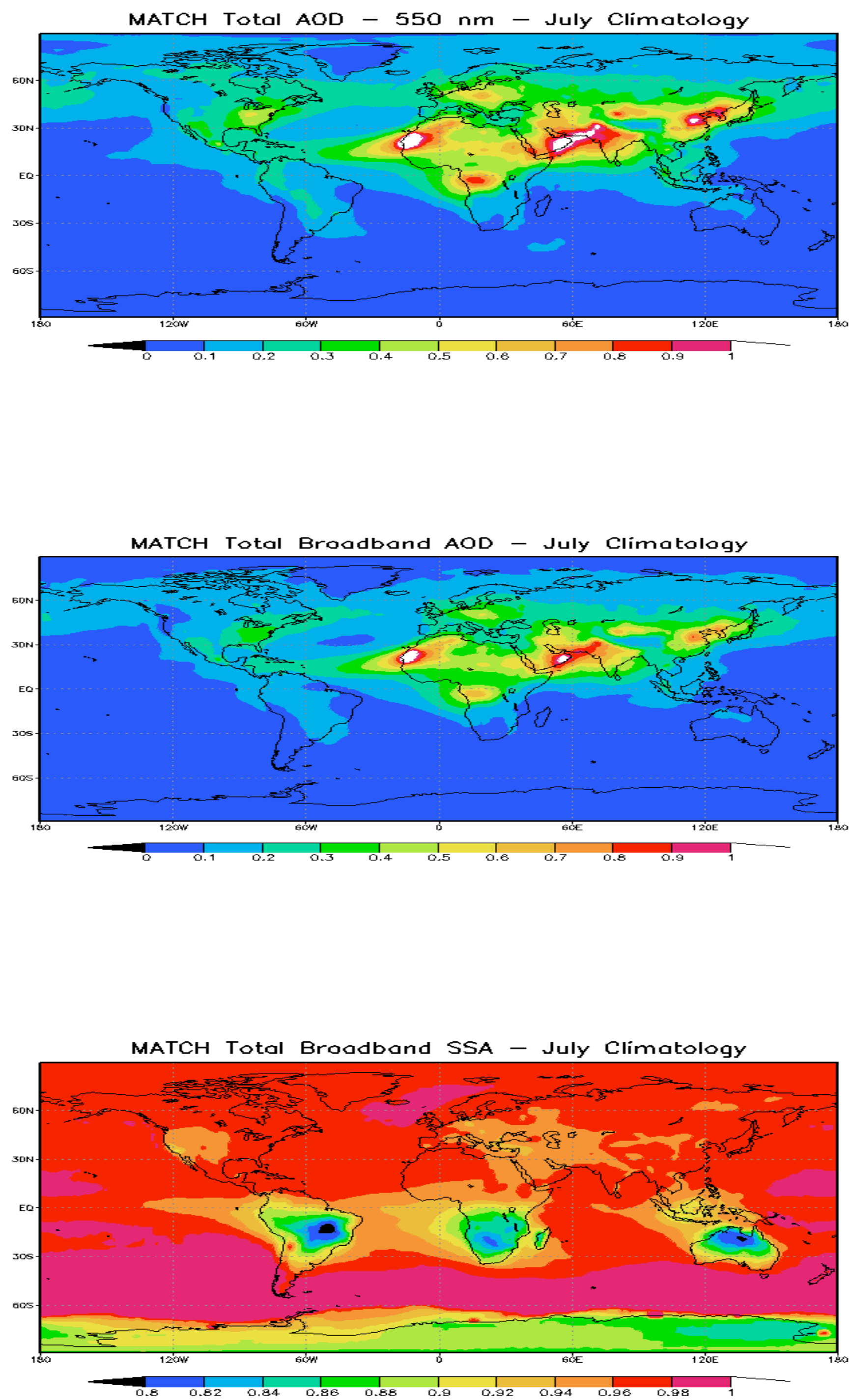
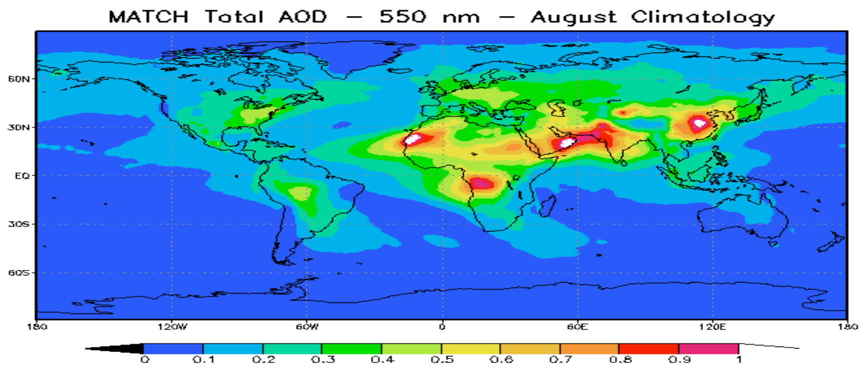
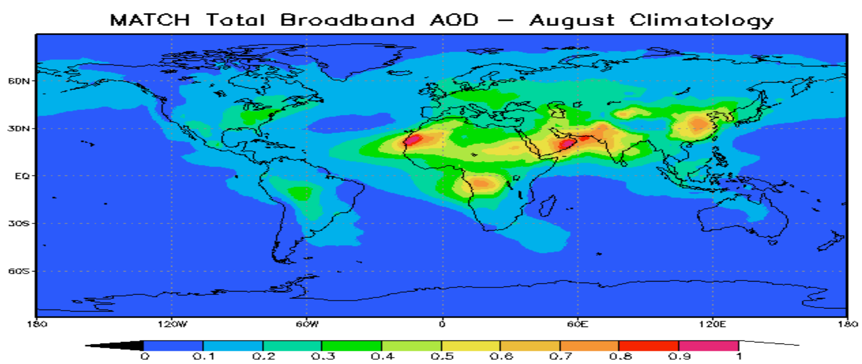


Figure 17. July Aerosol Climatology in SRBQC.





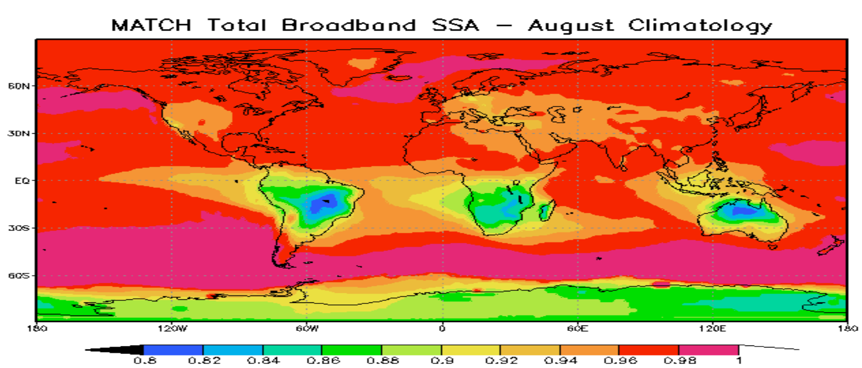
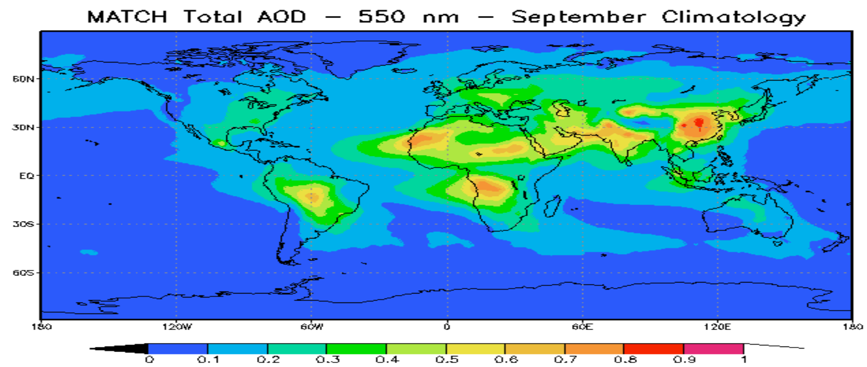
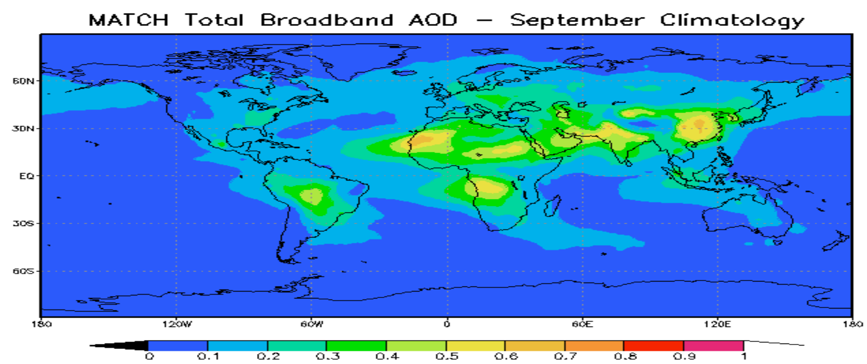


Figure 18. August Aerosol Climatology in SRBQC.





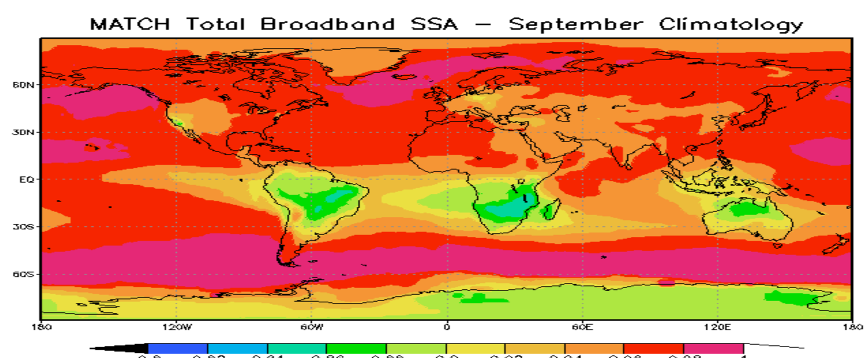


Figure 19. September Aerosol Climatology in SRBQC.

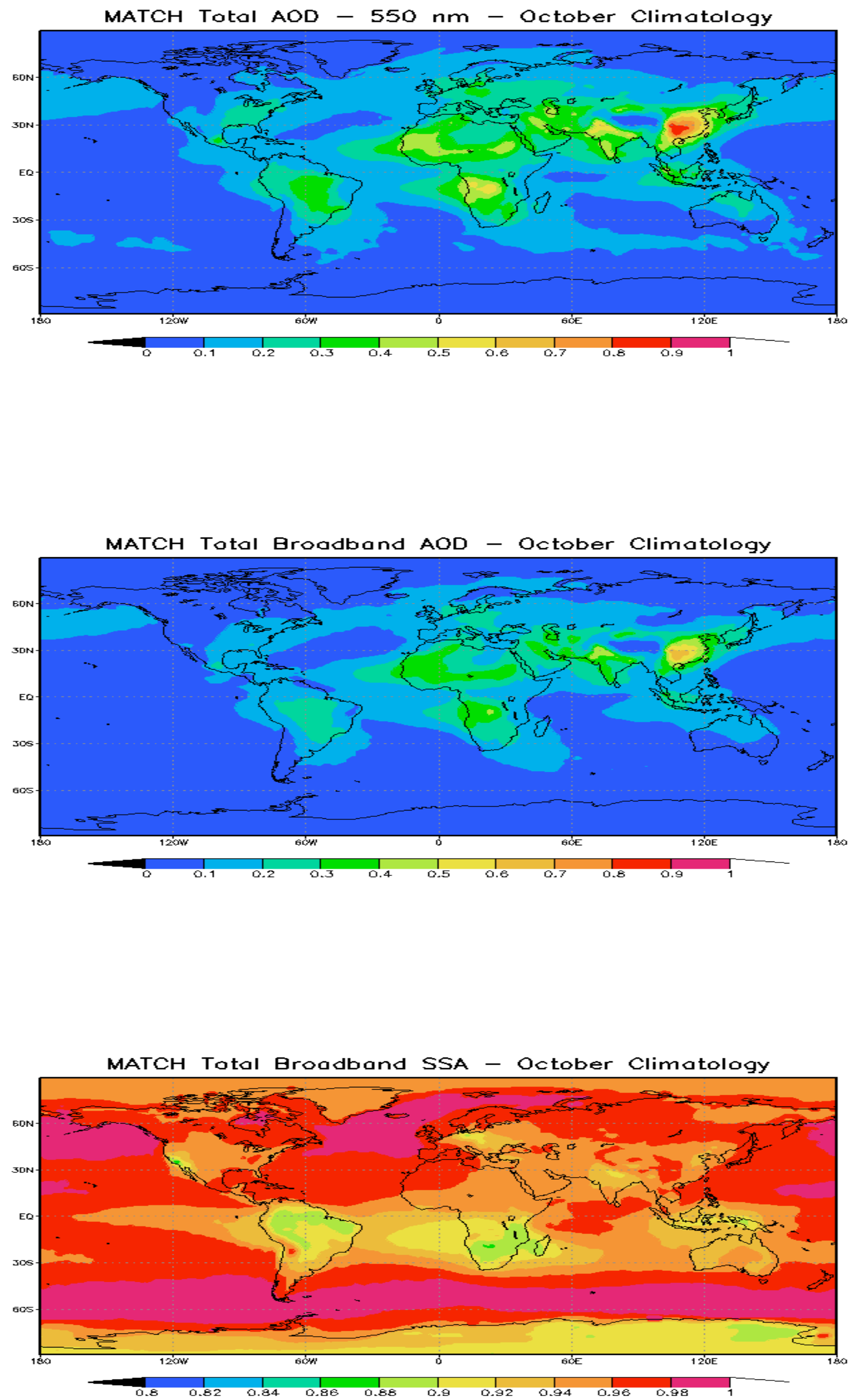
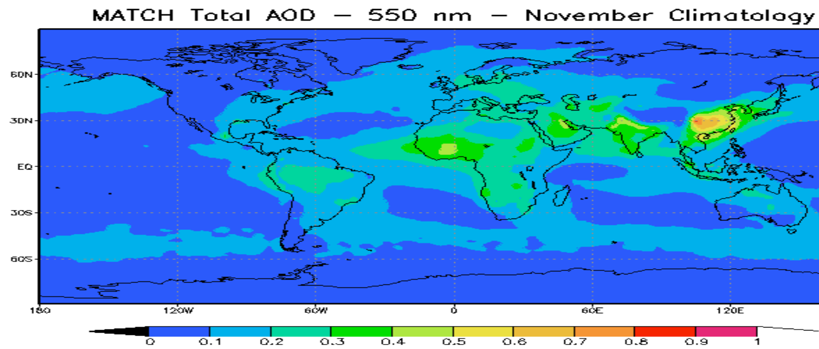
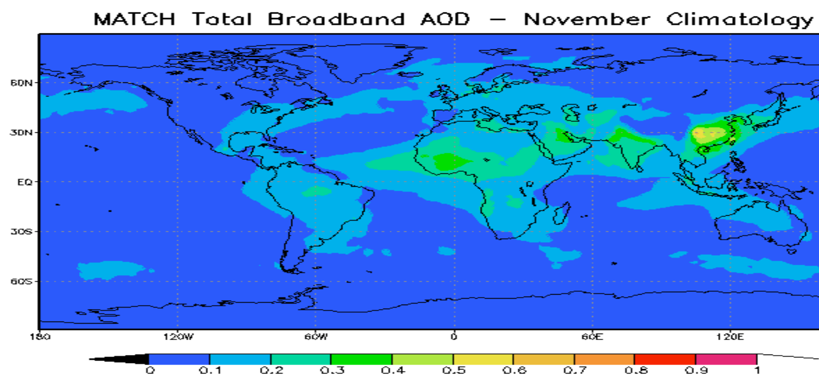


Figure 20. October Aerosol Climatology in SRBQC.





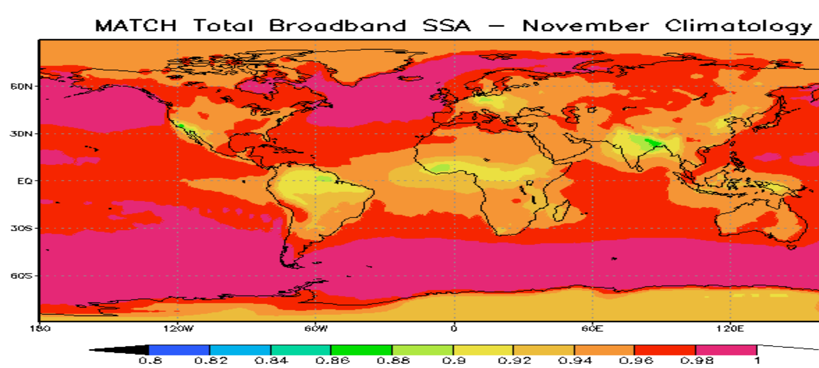


Figure 21. November Aerosol Climatology in SRBQC.

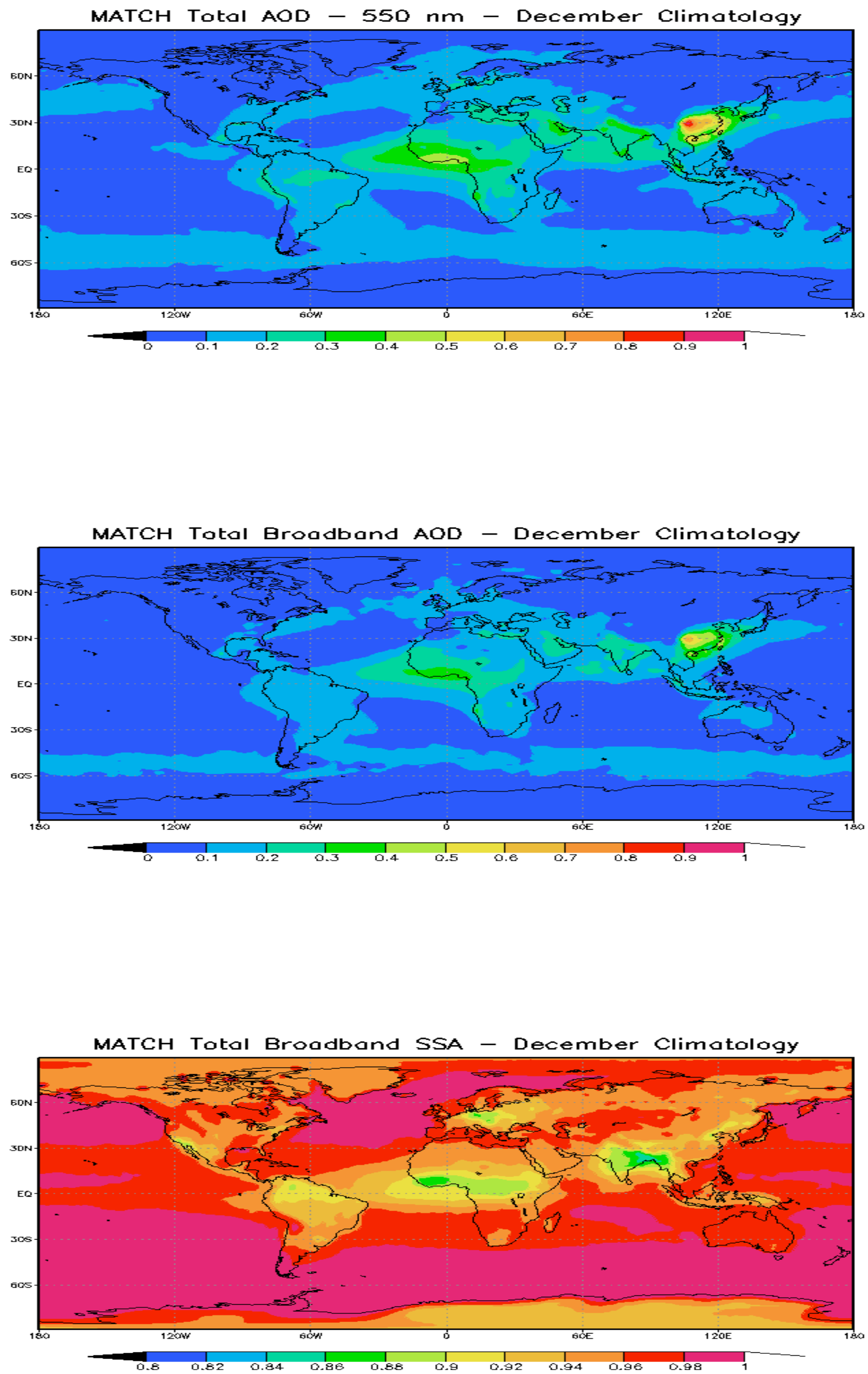


Figure 22. December Aerosol Climatology in SRBQC.

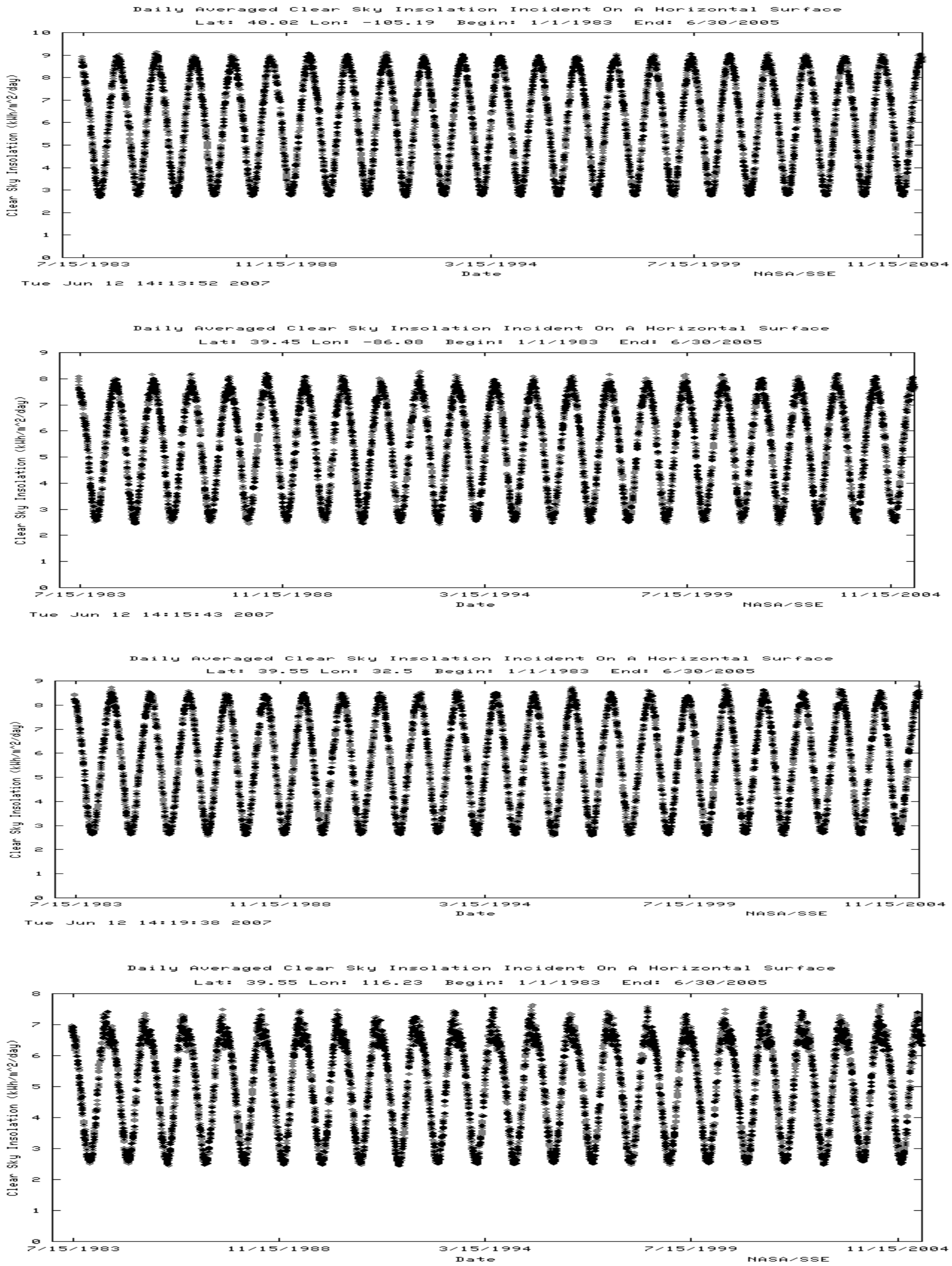


Figure 23. Estimated aerosol, precipitable water, and ozone variation on clear sky broadband radiation **at 40-deg North locations** (Top-to-Bottom: Boulder, Colorado; Indianapolis, Indiana; Ankura, Turkey; and Beijing, China).

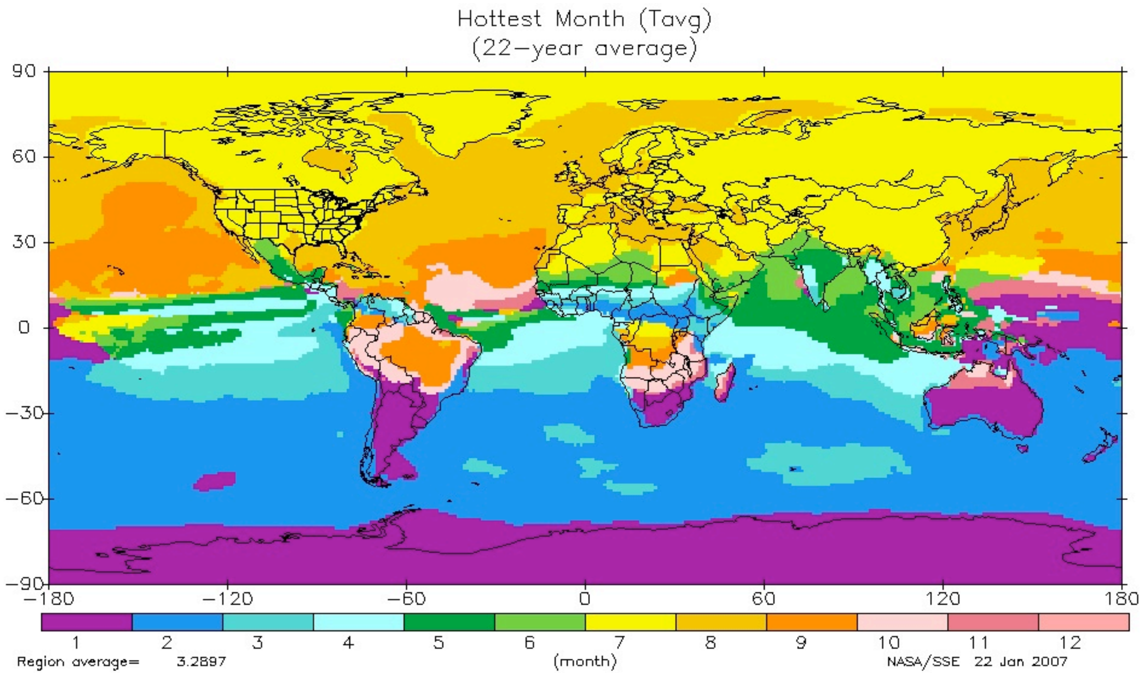


Fig. 24: Global distribution of the month with hottest 10-meter daily average air temperatures (Tave).

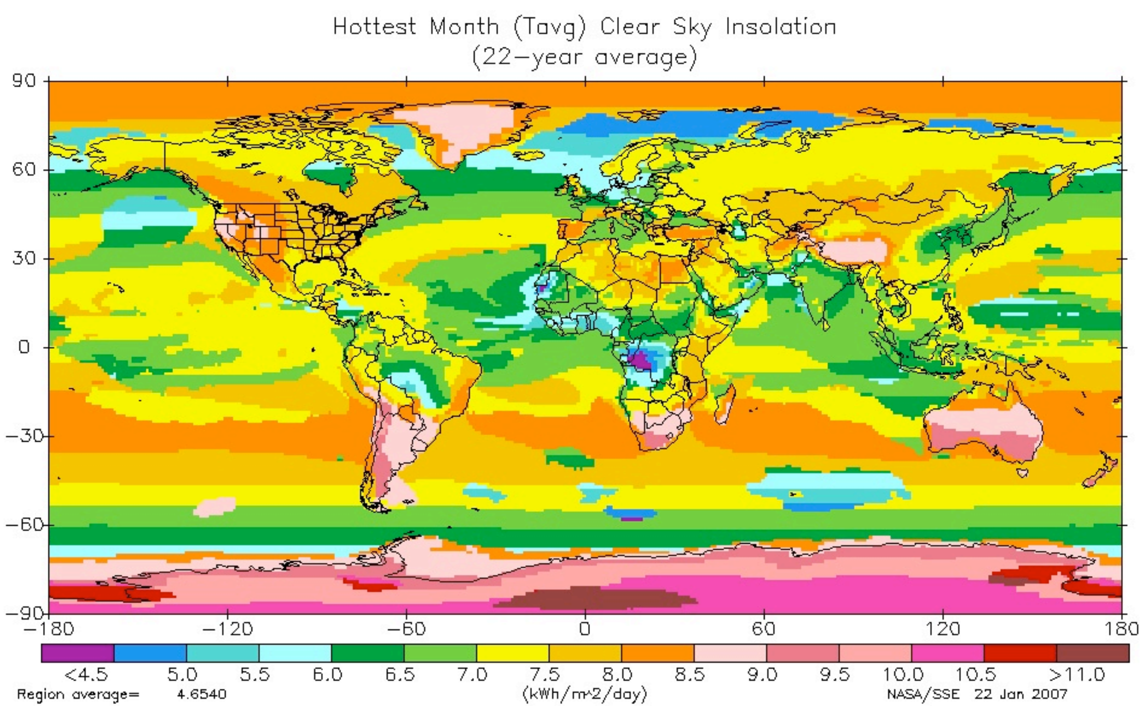


Fig. 25: Clear-sky monthly average SWDN on a horizontal surface for hottest month of the year.